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CORDLESS POOL CLEANING ROBOT

FIELD OF THE INVENTION

This invention relates to devices and methods for cleaning swimming pools, basins, and the like. More particularly, the invention relates to an automatic self-propelled cleaning robot powered by electrical rechargeable batteries.

BACKGROUND OF THE INVENTION

Battery powered pool cleaning robots are known in the art. They provide several advantages over robots that are powered via a power cable. The most apparent is that the cord is susceptible to entanglement as the robot makes the turns and rotations associated with normal scanning of a pool.

However, a battery operated robot has the limitation that the time needed for the robot to finish the entire scanning procedure is limited to the time the battery can power it between charges. In a regular (rectangular) pool, scanning the pool's floor is often performed according to the following algorithm: a robot traverses the pool floor until first encountering a sidewall; it then retreats from the sidewall in a direction perpendicular thereto, travels a predetermined distance, and rotates through 90 degrees; the robot further proceeds until encountering the next sidewall, and repeats the process until a certain number of 90-degree rotations has taken place; the predetermined distance is then increased and the entire procedure is continued until the scanning time is over, or until the predetermined distance equals half the distance of a full traversal of the pool. This results in Cartesian-like scanning, where the robot moves along two directions that are perpendicular to each other.

In an irregularly shaped pool, the above scanning algorithm will not result in Cartesian-like scanning. For example, when used in a circular-like pool, the robot adapted to perform such a scanning algorithm will mostly move in radial directions, due to which the center of the pool will be scanned more often than anywhere else, whilst it is likely that its periphery will not be scanned completely within the time allowed by the battery life.

A number of suggestions have been made for battery operated pool cleaning robots, which attempt to mitigate the limitation of a limited battery life. US 4,962,559 discloses a self-contained cordless electric pool and spa cleaner, which is maneuverable over both flat and highly contoured underwater surfaces. A pump impeller powered by an electric motor is used to draw water through a filter cartridge. The efficiency of the filter cartridge is said to be designed so as to allow for the use of a small motor and small battery which, in turn, result in the small size of the cleaner. All electrical components are enclosed in a watertight chamber so as to allow the entire cleaner to be submerged under water.

US 5,507,058 discloses a self-powered apparatus for automatically cleaning submerged surfaces, such as the floor and side walls of a swimming pool. The apparatus includes onboard sensors and an onboard processor (preferably, a microprocessor) which controls operation of the apparatus in response to status information supplied from the sensors. The apparatus has an onboard watertight battery and an adjustable inlet nozzle size, and includes left and right track treads which are controllable to cause the apparatus to turn or rotate (clockwise or counterclockwise), or translate in a forward or reverse direction, on a horizontal or vertically inclined submerged surface. The apparatus includes Hall effect transducers (with associated permanent magnets) and a microprocessor mounted within a sealed control assembly. The microprocessor is programmed to execute a selected one of a number of cleaning programs (thereby entering a selected operating mode) in response to exposure of the Hall effect transducers to a magnetically permeable card punched with specially arranged holes, or a card with a magnetically permeable insert molded within it.

US 5,454,129 discloses a self-powered pool cleaner with remote controlled capabilities. The cleaner includes a head having a lower base in a generally rectangular configuration with side openings extending vertically therethrough and an enlarged leading edge. The head also includes an intermediate cover positionable over the base with a central aperture extending therethrough with an apertured peripheral flange and a gasket positionable between the flange and the base. Also included is a top cover positionable over the intermediate cover and base for constituting a plenum zone. The top cover includes an aperture for coupling to a suction hose and an antennae extending upwardly therefrom. A brush is peripherally positionable downwardly from the lower face of the base. Parallel axles extending transversely through the base with drive wheels on one of the axles. Steering wheels are pivotally coupled to others of the axles with a steering rod for pivoting the wheels to change directions. A drive motor is within the housing to rotate the drive wheels. A steering motor is provided for axially shifting the steering rods. A receiver is within the base to drive the steering motor in one direction or another in response to signals from the antennae and receiver.

SUMMARY OF THE INVENTION

The present invention relates to a pool cleaning robot powered by at least one rechargeable battery and being free, during use, of any cables connected to an external power supply. The robot comprises a robot body with one or more batteries, a main controller, at least one brush, a drive means, a water inlet and outlet, an impeller, and a filter.

In accordance with one aspect of the present invention, the robot is provided with a tail unit comprising a head portion adapted to float at the surface of the pool, and a tethering cable, which is connected at one end to the head portion and at another end to the robot body, at least when the latter is in use. The tail unit may comprise a tail controller and a float user interface at the head portion. The tail controller may be in communication with the main controller in

the robot body via the tethering cable, and may be electrically connected to the batteries.

The float user interface may comprise at least one status indicator, communications port, and a power socket. The at least one indicator may be adapted to report the status of the filter, the battery, or whether the unit is on or off. The communications port may be used to download data from an external computer in order to update the software on the main or tail controller. It may also be used to upload diagnostic data from the robot. The power socket may be adapted to be connected to an external power source for charging the batteries or to power the robot, when desired.

The robot may be designed for connection to an external battery charger, with a charging cable to be connected to the tail unit to charge the batteries in the body unit of the robot. The charger may communicate with the main and tail controllers, and may have a charger user interface to display status information on one or more data presentation units in addition to or instead of the status indicator on the float user interface.

In accordance with other aspects of the present invention, the robot may be provided with one or more measures to facilitate completion of its scanning operation within the time allowed by the batteries between charges. One of the above measures is that the robot may be pre-programmed to stop at or near a sidewall of the swimming pool, in order to facilitate easy removal of the robot from the pool, e.g. by means of its tail unit. The robot may be adapted to proceed to a wall and stop upon determining that either an abnormal or a normal pre-determined condition has been met.

Another measure to facilitate completion of the robot's scanning is a selection of a least power-consuming wall detection mechanism. This may be accomplished by monitoring the electrical load on the drive means, alone or in combination with the use of a sensor such as a tilt sensor, or other mechanical device. Such monitoring is particularly useful when the vertical sidewalls of the pool are such that conventional climbing becomes impossible for the robot, such

as when they are covered with algae or are made of an especially smooth material.

Still other measures are special scanning algorithms, that may be designed to ensure efficient, e.g. Cartesian-like, scanning of arbitrarily shaped pools. Also, there may be provided a possibility of selection of different modes and/or parameters of scanning operations.

In accordance with further aspects of the present invention, methods of operating the robot having the above features are provided.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, specific embodiments will now be described, by way of non-limiting examples only, with reference to the accompanying drawings, in which:

Fig. 1 is a partial cut-away perspective view of a robot according to one embodiment of the present invention;

Fig. 2 is a partial cut-away perspective view of a tail unit of the robot shown in **Fig. 1**;

Fig. 3 is a perspective view of an external battery charger for a robot, such as shown in **Fig. 1**;

Figs. 4A and **4B** are block diagrams representing, respectively, operational relationships between the robot body shown in **Fig. 1** and the tail unit shown in **Fig. 2**, and between the latter unit and the battery charger, such as shown in **Fig. 3**;

Fig. 5A is an illustration of typical non-Cartesian-like scanning in an irregularly shaped pool; and

Fig. 5B is an illustration of Cartesian-like scanning method in an irregularly shaped pool, in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 shows an example of a robot **1** in accordance with one embodiment of the present invention. It comprises a robot body unit **10** and an optional tail unit **22**. The robot body unit **10** comprises a battery pack **12**, brushes **14**, a drive means with a motor **16** and tracks **17** connecting the motor to the ends of the brushes **14**, and a water outlet **19**. Not seen in Fig. 1 are a water inlet, an impeller, a filter and a main controller, which are housed within a housing **18** of the robot and are known per se. The main controller may be a chip protected from exposure to water and comprising a memory and a processor. In addition, the robot comprises a handle **20** which contains two floats for maintaining a balanced position during use on a pool's floor, and a diagonal position when cleaning at the waterline. The battery pack **12** is enclosed within a sealed compartment.

During operation, the impeller draws water from the floor or sidewall of the pool via the water inlet through the filter. The clean water is expelled through the water outlet. In addition to facilitating the cleaning of the pool, this process provides the force which keeps the robot against the pool surface. This is generally similar to the operation of known externally powered robots such as the one marketed under the name Dolphin by Maytronics, Ltd., Israel, except that the power source for the robot **1** is the internal battery pack **12** instead of external power delivered via a power cable.

Standard scanning may comprise cleaning the pool floor with or without ascending a sidewall. Cleaning with ascending the sidewall is well known, and one variation is described in US 6,099,658 (US '658). The robot **1** may ascend vertical sidewalls in order to clean them and the waterline, either according to a standard procedure, such as described in US '658 columns 3-4, whose description is incorporated herein by reference, or with a novel method of the present invention, which will be described herein.

The tail unit **22** is shown in more detail in **Fig. 2**, and it comprises a head portion **24** adapted to float on water, and a tethering cable **26**, which is attached

to the head portion **24** at its one end, and to the robot body unit **10** at its other end. The head portion **24** is shown to have a conical shape body **28** converging, when in use, downwardly, i.e. toward the pool floor, and a top portion **30** adapted to float at or above the surface of the water. The tethering cable **26** may be detachable from the robot body unit **10**, but, at least in use, remains attached and is of sufficient length to allow the head portion **24** to float near the surface of the deepest water in swimming pools for which the robot is designed. It may be suggested that the length of the cable **26** does not exceed 1-1/4 times the maximal depth of a standard pool. For example, the length of the tethering cable **26** may be between 2.25 and 2.5 meters. The tail unit **22** further comprises one or more counterweights **32**, adapted to maintain the floating working position of the tail unit during use. The head portion **24** may further comprise a float user interface **34** and a tail controller, which may be a microprocessor.

The head portion **24** is preferably designed to avoid entanglement with any obstacles. For this purpose, it may have a round cross-sectional shape at least in the area of its top portion to move easily around obstacles such as grip handles, traps, and ladder rails. In addition, the tail unit **22** is sealed against water entry, which allows it to dive below the water when encountering obstacles such as floating lane ropes, allowing for free continuous operation. The diving is accomplished by the shape of the head portion **24**. When the head portion **24** encounters an obstacle on the surface of the water, the robot body unit **10** continues operation, pulling the tethering cable **26**. When the tethering cable **26** becomes taut, the head portion **24** slides below the surface of the water to circumvent the obstacle.

The head portion **24** of the tail unit **22** has a float user interface **34** which may comprise one or more data presentation units **38**. These units may be lights or light emitting diodes, controlled by a tail controller (not seen in Fig. 2) to indicate, for example, the unit power status (On/Off). The float user interface **34** may further comprise at least one socket **40**, that is sealable and adapted to receive external connections. These external connections may include, but are

not limited to, a charging cable and/or a communications cable, which can be used to download software updates to the controller and upload diagnostic data from the robot's main controller. The user interface may further comprise a power switch **42**. In order to enable many of the aforementioned functions, the tail controller is in communication with the robot's main controller via an integrated communications cable in the tether cable **26**.

The float user interface **34** further comprises an antenna **36** adapted to receive commands from a wireless remote control unit. This remote control unit may be adapted to perform different functions, including one or more of the following:

- choose the mode of cleaning operation of the robot;
- cause the robot to move in a direction directed by a user and independent of scanning algorithm;
- predetermine the cycle time; and
- select the length of a pool to be scanned.

The robot **1** may be provided an external battery charger **44** shown in **Fig. 3**. The charger **44** comprises an external cable **46** adapted for connecting to an external power source, and a charging cable **48** adapted for connecting to the socket(s) **40** of the head portion **24** for charging the robot **1**. In addition, the charger **44** and the tail unit **22** communicate via the charging cable **48**. The charger may further comprise a charger user interface **50** and an On/Off switch **52**. The charger user interface **50** may comprise one or more data presentation units **54**. These units may be lights or light emitting diodes, to be during charging to indicate the status charging and the status of one or more parameters of the robot. These parameters may include, but are not limited to, filter status and battery status. The charger user interface **50** may further comprise a reset switch **56**, which is used to reset the main controller's filter monitoring when the filter is cleaned or changed. Some or all of the elements described in reference to the charger user interface **50** may optionally be located on the float user interface **34**.

Figs. 4A and **4B** illustrate a block diagram of the main and tail controller, and of the battery charger, and elements of the robot to which they are related. The block diagram of **Fig. 4B** is an expansion of the block labeled "Robot" in **Fig. 4A.** The block diagram is self-explanatory and, therefore, no detailed description thereof will be provided.

The tail unit **22** is preferably adapted for raising thereby the robot body unit **10** from the floor of the pool to the surface. To make sure that this is easily achievable, the robot may be pre-programmed to terminate operation, when necessary, near a sidewall so that the tail unit **22** floats within the grasp of a person standing outside the pool. The robot may be pre-programmed to terminate operation when at least one of several normal or abnormal conditions occurs. These conditions may be that no or little more useful scanning can take place, due to, for example, the completion of the scanning procedure, or the fact that the battery power or voltage has dropped below a predetermined threshold, or the fact that the filter is covered with retentate to the extent that no more useful filtering can be accomplished. The tail unit **22**, when connected to the charger **44**, may be designed to display which condition has been met. Alternatively, the robot may stop after a predetermined number of wall detections have occurred once the at least one condition is met.

The tail controller may be adapted to monitor the battery charging process and to allow for full battery charging while disconnecting power-consuming components, minimizing unnecessary use of power. It may detect overheating conditions during charging and protects the battery from over-discharge. It also may maintain a minimum power consumption when the robot is not involved in a cleaning cycle. In this way, certain components of the robot, such as data presentation units, will still function even after the cleaning cycle has completed.

The main controller may be preprogrammed to perform scanning according to one of several algorithms. Ideally, when a swimming pool is scanned, its entire floor area should be scanned without, or with a minimal, overlap so as to perform the scanning in the shortest time. Based on this, the

efficiency of robots for cleaning swimming pools is evaluated by measuring the time it takes the robot to completely scan a given swimming pool.

As mentioned before, scanning of swimming pools may be either Cartesian-like or non-Cartesian. A Cartesian-like scanning pattern in which robot moves mostly in two mutually perpendicular directions, is known to be obtained in rectilinear pools with four mutually perpendicular walls, with a conventional scanning algorithm, as described in the Background of the Invention,.

The same conventional algorithm, however, results in a non-Cartesian-like scanning pattern when used in a pool of a non-rectangular shape as illustrated in **Fig. 5A**. In it, the robot starts from a location **S1** and travels in a straight line until it detects a wall at point **W1**, then it retreats from the wall in a direction that is generally perpendicular to the tangent thereto at the point of impact and it travels for a predetermined time **T**, after which it rotates through a 90 degree angle at point **R**, and travels in this direction until the next wall detection occurs at point **W2**. The robot then repeats this procedure until a predetermined number of wall detections has occurred, after which the time **T** is increased. Since in an arbitrarily shaped pool, the walls form arbitrary angles with adjacent walls, the directions in which the robot will retreat from the wall after different wall detections are likely to be completely different from one another, resulting in a non-uniform scanning of the pool. For example, as illustrated in **Fig. 5A**, in a circular or oval pool, most of directions in which a robot is bounced from the pool's walls are radial, i.e. pass through the pool's center. Thus, in such a pool, the area close to the pool's center will be scanned more often than areas closer to the pool perimeter, whereby no uniform scanning may be achieved, and no efficient power consumption may be obtained.

In view of the above, the procedure may be provided, in accordance with one of the aspects of the present invention, to allow Cartesian-like scanning of an irregularly shaped pool, as illustrated in **Fig. 5B**. To perform this procedure, the robot body unit **10** is provided with a means known per se for detecting its orientation. Such means may be, for example, in the form of a digital compass

integrated onto the main controller in the robot body unit **10**. Once the robot **10** is located in the swimming pool to be scanned, the absolute orientation thereof is measured and stored as a reference orientation. This orientation may be that of the direction of travel of the robot in relation to magnetic north. With reference to **Fig. 5B** the robot then moves along, keeping its original orientation from a starting location **S2** until it first impacts a wall of the pool at point **W3**. It then retreats from the wall in a direction that is perpendicular to the tangent thereto at the point of impact, as in standard cleaning procedures. In accordance with one of the aspects of the present invention, the robot subsequently rotates at point **R1** until it is realigned with the reference orientation. Subsequently, the realignment will take place upon every wall detection to orient the robot to move parallel to the direction in which it moved at the reference orientation, or to move perpendicularly to the direction it moved with the reference orientation.

In particular, as seen in **Fig. 5B**, during the course of the scanning, the robot body unit **10** thus performs the following kinds of laps between wall detections. The first lap comprises the robot body unit **10** traversing the pool after one wall detection, aligned with the reference orientation as described above, and keeping the corrected orientation until the next wall detection. This is referred to as a straight lap, designated as **STR** in **Fig. 5B**. The second lap comprises the robot body unit **10** traversing the pool after one wall impact, realigning itself to the reference orientation as described above, keeping the corrected orientation for a certain period of time, and then rotating through approximately 90 degrees to continue moving in this orientation until the next wall impact. This is referred to as a stepped lap and it is designated as **STP** in **Fig. 5B**. Since the direction of the robot body unit **10** has been altered by 90 degrees, the robot body unit **10** must align itself accordingly subsequent to the next wall impact. Therefore, subsequent to the wall impact after the first 90 degree rotation, the robot body unit **10** realigns itself to the reference orientation plus 90 degrees. Subsequent to wall impacts after successive 90 degree rotations, the robot body unit **10** alternates between realigning itself to the reference

orientation and realigning itself to the reference orientation plus 90 degrees. In this way, it is ensured that after all wall detections, the robot body unit **10** will realign itself in two mutually perpendicular directions, whereby a Cartesian-like scanning pattern is realized, which provides a plurality of advantages compared with conventional non-Cartesian-like (labyrinth) patterns, for irregularly shaped pools. The increased efficiency of this method allows the robot to complete its cleaning cycle in less time, which may allow for a smaller battery pack to be used.

The period of time before the rotation in each stepped lap may vary depending on the full duration of the preceding straight lap, and it may constitute a portion of this full duration. This portion may be chosen as small at the beginning and then increased after a predetermined number of wall detections have been registered. Alternatively, it may be originally chosen as large and then this portion is decreased.

In particular, the time before the rotation in each stepped lap may initially be chosen as one half of the duration of the preceding straight lap. This time will be reduced on each subsequent cycle by an amount which is typically less than one quarter, and can be expressed as $1/n$, where n is an integer. If, for example, $n=8$, and the duration of the preceding straight lap was 40 seconds, the time before rotation in the stepped lap immediately following the straight lap is 20 seconds (one half of the duration of the straight lap). The time before rotation in each further stepped lap will be one half of the duration of its preceding straight lap until the number of wall detections reaches a predetermined number. Then the period before rotation will become 3/8 of the preceding straight lap, so that if the last straight lap had duration of 40 seconds, the robot will next rotate 15 seconds (3/8 of 40 seconds) after a wall detection following a straight lap. The same procedure may be further repeated with the period before the rotation in the stepped lap being decreased to 1/4 and then to 1/8 of the duration of the preceding straight lap. This method has some advantages over that where time before rotation is first small and then increases as in typical Cartesian-like

scanning among which is that a user will readily see the robot actively starting its scanning when operated.

Alternatively, the time before the rotation in each stepped lap may initially be any amount less than one quarter, and can be expressed as time before the retention in each stepped lap $1/n$, where n is an integer. If n=8, and the duration of the preceding straight lap was 40 seconds, the time before rotation in the stepped lap immediately following the straight lap is 5 seconds (1/8 of the duration of the straight lap). The time before rotation in each further stepped lap will be 1/8 of the duration of its preceding straight lap until the number of wall detections reaches a predetermined number. Then the period before rotation will increase, i.e. become 2/8 of the preceding straight lap, so that if the last straight lap had duration of 40 seconds, the robot will next rotate 10 seconds (2/8 of 40 seconds) after a wall detection following a straight lap. The same procedure may be further repeated with the period before the rotation in the stepped lap being increased to 3/8 and then to 1/2 of the duration of the preceding straight lap.

After a predetermined number of wall detections have occurred in each cycle, one extra straight path may be made to make an additional wall detection prior to the increase of the period before rotation in the subsequent stepped laps. The direction of rotation may be changed for such subsequent stepped laps relative to that of the previous stepped laps.

The Cartesian-like scanning pattern as described above for arbitrarily shaped pools, where the scanning is performed along two mutually perpendicular directions obtained by adjusting the robot's orientation each time after wall impact, has appeared to be surprisingly much more efficient than the non-Cartesian-like scanning pattern. It appears to reduce the totals by at least 30% of the scanning time for similar coverage using a standard scanning time method.

The robot **1** may perform several additional modes for scanning the surface of the pool floor and vertical walls.

One such mode may provide for the robot to scan the floor of the pool according to a given procedure, e.g. based on a labyrinth algorithm. After a

predetermined period of time, the robot may ascend a vertical sidewall and scan the waterline for a predetermined period of time, after which it descends to the floor and continues scanning. The robot can be programmed to scan according to this or any other method, at an 'intensive' cleaning mode with the speed of the robot decreased, and the suction increased. The robot can be programmed to perform a "wall cleaning mode" by, e.g. ascending a vertical sidewall to the waterline, cleaning the waterline for a predetermined amount of time, descending the sidewall to the floor, moving along the sidewall a predetermined distance, ascending the sidewall, and continuing cleaning in the first direction. This cycle may be repeated a predetermined number of times, subsequent to which the robot proceeds to the next wall and continues the repeats the cycle there.

In order to ensure that a sidewall is always properly detected by the robot, a new method of sidewall detection is suggested. Currently, pool cleaning robots typically register sidewalls by utilizing a tilt sensor, or other mechanical device which detects when the robot begins to ascend a sidewall. The tilt sensor is typically a solid object with a tubular hollow therein. The hollow is V-shaped, with its vertex at the lowest point, and runs along a single plane which is parallel to gravity. A small sphere is disposed within the hollow, and rests, when in a non-tilted position, at the vertex. An optical sensor detects the presence or absence of the ball. When in a tilted position along the plane, the sphere rolls away from the vertex, and a tilt is detected. This type of tilt sensor is currently used in the robot sold under the name Dolphin by Maytronics.

The tilt sensor requires that the robot begins to ascend the sidewall in order for the tube to change position. However, in pools with very smooth sidewalls or an algae covering on the sidewalls, the use of a tilt sensor to effect a sidewall detection becomes ineffectual, and, as an alternative way suggested hereinfor, sidewall detection is based on peak current detection. For this, the robot's main controller may be designed to continually monitor the current passing through the drive motors. When the robot encounters a sidewall, the current passing through the drive motor increases sharply. The rise is analyzed,

and when a threshold is reached, the main controller registers a wall detection. The threshold is determined by determining an average floor current level, which may be predetermined or established at the beginning of a cleaning cycle, as follows: the robot having both a peak current detector and convention wall detection means, e.g., a tilt sensor, is allowed to traverse the pool until such a long time has passed without a reversal due to a sidewall detection that it is assumed that a sidewall impact has occurred, and that the impact was not detected by the conventional means. At this point a reversal takes place, and, after a brief period of time has passed, the controller measures the current passing through the drive motors. This brief period of time is enough time for a reversal to take place, and may be on the order of five to ten seconds. This process may be repeated several times to obtain an average floor current value, which is then multiplied by a constant to obtain the threshold value.

Alternatively, a robot may have the peak current detector as its sole means of sidewall detection, at least in such cases wherein it is known that ascension of sidewalls is impossible. When sidewalls may be ascended, the peak current detector may be used as the sole means of sidewall detection when an appropriate threshold is predetermined.

Those skilled in the art to which this invention pertains will readily appreciate that numerous changes, variations and modifications can be effectuated without departing from the true spirit and scope of the invention as defined in and by the appended claims.